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ABSTRACT

An overview is provided of the principles of cognitive psychology that can be used to enhance the effectiveness of computer-assisted instruction (CAI). First, the paper looks at the features of classical and operant conditioning that provide the foundation for important parts of mastery learning and CAI programs. Next, findings from four areas of cognitive psychology research and theory are discussed in terms of their applicability to CAI: (1) modern knowledge about how people learn concepts, retrieve them from memory, learn to discriminate among similar concepts, and apply their knowledge of a concept to unfamiliar situations; (2) human limits in memory, attention, and mental processing; (3) the role of goals and performance standards in cognitive processing; and (4) principles of remembering and forgetting that stress the importance of relevance, organization and integration, elaborated processing, the match between conditions at learning and conditions at retrieval, and memory erosion and interference. Within each section, and in a separate summary, research-based suggestions for CAI development and practice are presented (e.g., when teaching concepts, present a set of positive examples covering the range of instances that fit the concept to help students generalize new examples, and present a set of negative examples to help students discriminate among superficially similar concepts; provide the student with control over the program; define ultimate and short-term instructional goals; and provide edit and correct practice). (EJV)

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HOW THE USE OF COGNITIVE PSYCHOLOGY FINDINGS CAN RAISE THE PRODUCTIVITY OF COMPUTER-ASSISTED INSTRUCTION

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Paper presented at the National Conference of the League for Innovation in the Community College
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HOW THE USE OF COGNITIVE PSYCHOLOGY FINDINGS CAN RAISE THE PRODUCTIVITY OF COMPUTER-ASSISTED INSTRUCTION

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INTRODUCTION

When scientists explore new phenomena and discover new cause and effect knowledge about nature, they are followed by engineers who try to find ways to use that knowledge for human benefit. Thus physicists, chemists and biologists have produced knowledge that has been successfully used by mechanical, electrical and genetic engineers. Similarly, psychologists have discovered important knowledge about personality and behavior, which has been utilized by therapists to help clients and by teachers to help students. In particular, psychologists have made many discoveries about learning, memory, attention, and motivation which have been used by educators. As a result we have seen such important educational applications as improved instructional design; better techniques of teaching physical skills; good how-to-study information for students; powerful direct instruction techniques for teaching reading, spelling and math in the lower grades; effective humane discipline systems in the schools; mastery learning; and of course computer-assisted instruction.

My general assumption is this: If we study how reality works and adjust our behavior to it, we can get more of what we want. For example, one reality about water is that it flows easily and is easily stopped by barriers. If we build channels for it and remove barriers, we can make it go where we want it to go. Likewise, if we understand the realities of people's thinking and learning, we can build channels for their thoughts and help them think and learn what they want to. We use the nature of a reality and get more of what we want.

Classical Conditioning: From the psychological behaviorists educators have learned classical and operant conditioning. Classical conditioning is a means of teaching concepts. Teachers take naturally existing stimulus and response sequences and attach new stimuli to them. For example, a teacher shows a child a picture of a large brown and white animal that says "Moo" and gives milk. The picture is already linked to memories of real cows for some students. The teacher links the word "cow" to the picture, so that the new stimulus "cow" evokes the mental imagery and facts about cows. Several years later the concept of "mammal" will get linked to cows. And so on. New stimuli get conditioned to familiar stimuli so that they elicit familiar responses.

Operant Conditioning: Many teachers have also learned operant conditioning,

probably from B. F. Skinner, and can teach skills effectively. CAI programs use it often. For example, a certain French practice program provides the stimulus of a sentence, asks the student to convert it from positive to negative form ("ne . . . pas"), so the student writes it in, and the program gives feedback. CAI writers have learned to provide a discriminant stimulus, induce a response, and provide positive or negative reinforcement or a punishment or no reinforcement at all after the response. Frequent repetition is used to make the response tendency strong. Likewise, writers of computer games and simulations can use both point systems and the natural consequences occurring in games to provide reinforcing or punishing stimuli to teach correct responses.

Conditioning and CAI -- A Mixed Record: Such principles and many others from behavioral psychology provide the foundations for important parts of mastery learning programs and computerassisted instruction. CAI has been able to exploit the potential of computers to teach many concepts and skills effectively. It is a massive achievement which educators and students have benefitted from.

CAI is more productive when it conforms to the principles of classical and operant conditioning. Unfortunately, some CAI material still violates elementary knowledge from behavioral psychology. For example, it is known that people can learn to make correct responses to new stimuli much faster if they see familiar stimulus and response sequences before the new stimulus is brought in. I saw a grammar program that had NOT yet defined "subjects" and "predicates" and "complete thoughts" (not familiar stimulus-response units) use those terms to define a sentence (a new stimulus) and try to use the definition. When principles are taught before teaching the component concepts, then classical conditioning is fragile and haphazard. (By the way, don't confuse this bad practice with the acceptable technique of using undefined terms in introductory summaries, or of naming new terms when they will be followed immediately with examples and definitions.)

Sometimes CAI violates known principles of operant conditioning. For example, the goal of operant conditioning is to have the student see specific situations and emit the right response numerous times and be rewarded often enough that learning occurs. Yet I've seen an Electronics tutorial program that asks questions, and when it gets a wrong answer, it merely says "No" in various ways, states the correct answer and goes on. No return to the question or to a set on the topic later. Therefore, there's little of the needed sequence of stimulus--action--reinforcement. And that means that the student learns incompletely and forgets rapidly.

While I'm trying to illustrate the point that when teaching violates known principles, it interferes with students' learning, I'm also building to a related point. If teaching violates unknown principles, it also blocks effective learning. It is important for instructors to know how people learn. Ignorance of the law is no excuse. If channels are not dug for water, it won't flow where you want it to go. And you generally will not find this information about principles in CAI authoring systems. They usually assume that teachers already know the principles of effective instructional design.

Cognitive Psychology -- A New Source of Teaching Principles: Beyond classical and operant conditioning, there are still more principles available, supported

by strong evidence, that are waiting to be used more frequently. They can be found in the broad area of research and theory commonly called cognitive psychology. I have been reading cognitive psychology books and articles for the past several years, and they have convinced me that there is much more knowledge about learning and memory available for educators than can be found in classical and operant conditioning research.

If this knowledge is used, we can expect an increase in productivity--the ratio of output to input. A CAI writer can use shorter lessons incorporating powerful psychological principles (the input) and get the improved output of greater student discrimination of concepts, longer memory, better access to memory, greater transfer and generalization to new situations. The CAI writer's productivity has then increased.

I want to describe some of these cognitive psychology findings to you and suggest some applications to CAI. Our lack of time causes us a problem. I cannot teach you these principles, in the strict sense of the word. Neither of us have time today. But I want to help you appreciate the potential value of these findings for making CAI more productive. I suggest that you set two goals for yourself: (1) As you listen to the principles and the few applications I describe, try to decide if some of them are practical and useful to build into CAI. I hope you will keep clear the difference between the proven principles and my suggested applications to CAI. Although you may conclude some of my applications are impractical, you can still respect the principles and can try to think of ways to use them. (2) Try to estimate whether it's worth your time to search for more findings.

Common tutorials and drill and practice lessons that are based largely on behavioral psychology have some common patterns. They sub-divide lessons into little units. Usually the units are chosen and rationally sequenced on the basis of a task analysis of the skills, sub-skills, and prerequisite knowledge that is needed for success. Brief expositions are given. Examples are given. Then practice and testing are provided with feedback. The feedback varies in detail from simple Yes and polite versions of No responses to elaborate branching and re-teaching schemes.

What could a person who knew some cognitive psychology add to this common format?

CONCEPT LEARNING

The first thing might be to apply modern knowledge about concepts: how people learn them, retrieve them from memory, learn to discriminate among similar concepts that could be confused with each other and learn to generalize their knowledge of a concept from the teaching examples and definitions to unfamiliar examples.

According to cognitive psychologist John Anderson the most adequate model of the information people that use to decide what instances to put in categories is "the feature-set model." As people observe instances of events in the environment, they notice and remember what sets of features tend to occur together in a category. They develop their concepts and categories around these sets of features. Since certain instances are more typical or more normal than others, people think of them as prototype instances or

examples of the concept. For example, as North Americans observe birds which range from hummingbirds and sparrows to condors to herons, they would tend to think of robins as prototype birds.

Moreover, it seems that people need to pay conscious attention to the concept characteristics. They can't learn well automatically, unconsciously, or inattentively. In fact, Anderson says that people need to make mistakes in classifying examples before they can discriminate accurately among positive examples and near misses.

People can be assisted in forming categories by studying definitions, which focus on the key features that characterize a concept. However, there is a problem. People do not easily remember exact words. The precise wording of information fades quickly, leaving only a general sense of its meaning. Moreover, people do not reliably make vivid and accurate mental images of concepts from studying definitions alone. Therefore, they need extensive help by seeing a wide range of examples. They also learn from sstudying "near misses" as to what similar phenomena are not examples of the category.

This area of findings has some implications for CAI. CAI modules that teach concepts need to help students consciously focus on the sets of features shared by examples of category members; they probably need to test students and let them make mistakes in order build discrimination; and they need to provide a wide range of examples; they should urge students to focus on prototype examples and remember them. CAI writers have to help students overcome their problems of forgetting exact words, neglecting to make images of examples, not discriminating among a concept's examples and near misses, and not generalizing easily to unfamiliar instances of a concept.

When people learning a concept have available a formal definition and a set of positive examples and negative examples or near misses, they can use a combination of deduction and induction. From the definition they can obtain the feature set of defining concept characteristics. From positive examples they obtain a few specific instances that form points in the range of potential concrete instances of the concept. When they later see new instances which might or might not be instances of the new concept and need to generalize their knowledge, they can interpolate the new instance into the range of examples from the teaching set. They can also extrapolate from the teaching set to new instances. And from the negative examples, which are things that look like instances of the concept but which are not, they obtain limits. They learn to discriminate true instances from false instances.

If I were explicitly teaching you about concept learning, I'd proceed differently. But for this talk, I'll confine myself to one positive example. If I were teaching about mammals, I would list the set of features defining the category. For instance, mammals are the highest class of vertebrates, including humans; they have mammary glands and nourish their young with milk; they usually have skin covered with hair; they are warm-blooded; and except for the monotremes, they give birth viviparously. (I'll skip a few other traits.) The next teaching step is to give a range of positive examples such as cows, dogs, mice, elephants, bats, kangaroos, platypuses, whales, porpoises. Notice the range: big and little, land-living, flying, swimming, and a marsupial and a monotreme. For negative examples or near misses, one would mention animals that are not mammals: snakes, penguins, other birds, fish,

sharks, lizards and so on. While teaching one would continually point out the key concept characteristics. I would also suggest that students focus carefully on cows, perhaps, as good prototype examples. After that, students would practice matching examples to concepts.

What happens if a teaching program omits some of this material? Leaving out the "far-out" positive instances leads to students thinking that only normal examples are members of the category, and they will be incapable of generalizing the category enough. Leaving out negative examples or near misses leads to some students mistakenly including look-alikes into the category. They might classify penguins as mammals. They generalize too much; they don't discriminate among categories adequately. Leaving out prototype examples forces them to rely on the verbal definition and slows their recognition of members of the category. Or having seen several examples, none a prototype, students forget them all. They might on a test inefficiently try to recall the verbal string of the definition rather than deftly retrieve the integrated visual image of a prototype. From the visual image of the prototype they could scan for the concept characteristics and retrieve or reconstruct the verbal definition. Another example: students of sociology often fail to discriminate social norms (specific rules) from values (idealized conceptions of what is desirable) when all they've learned is a verbal definition and a few positive examples. They discriminate too much. Or in the example of mammals, they might mis-classify bats or kangaroos as not mammals.

You can find this material and much more under the topic of concept learning in cognitive psychology books. It is also well- expressed by Wesley Becker, who comes from a behavioral psychology tradition, in Applied Psychology for Teachers.

OVERLOAD

Now a problem: overload. Concepts often have to be taught in groups, sets, lists. That can run up against the limits of people's memory and attention capacities. Overload hinders learning, and cognitive psychologists have found out a lot about overload.

When people are learning new concepts and skills, they have to consciously attend to the features of concept examples and to their own actions. That slows them down at first and leads to many mistakes. It takes a reasonable amount of repeated practice for people to be able to handle many perceptions automatically at the unconscious level. Similarly, the short-term memory can hold about 7 unrelated, unfamiliar bits of information -- plus or minus a couple. And the short-term memory lasts about 15 to 20 seconds without rehearsal. When people see events or read prose or hear speech, they rapidly forget exact details of shape, color, sequence, word choice and so on, but they do recall the general meaning of the events.

If a CAI lesson introduces a lot of material in a short period of time, its users will forget most of it. I saw this happen in a CAI module teaching people how to tell when subjects and verbs in sentences were agreeing. It first made the basic points that single subjects call for singular verbs, and plural subjects call for plural verbs. Then it introduced 9 complex situations in a row. They covered such topics as 2 subjects where one is singular

and one plural, collective nouns like "committee", and singular subjects with "s" on the end like "measles" and "physics". 9 situations! After that and some more tutorial, it went to the drill and practice. Using that program a student who had been overloaded had no way to recall the list of principles on command. Obviously, if CAI ignores human processing limits, it confuses people's learning and it slows it down. Lower productivity.

How can CAI adapt to human limits in mental processing? There are several techniques possible, each useful in certain situations.

1. Introduce just a few concepts, facts, procedures at a time.
2. Provide practice in order to build discrimination, memory, and integration into the cognitive skills needed for the tasks that will be used later.
3. Add new concepts, one or two at a time, to the set of concepts to be learned. Then provide more practice over all the concepts in the enlarged set. This is called "cumulative addition to a set." Do not practice new topics only in isolation from one another.
4. When a CAI author must refer to a concept that may have been forgotten, provide a brief reminder of its meaning. This reminder can be a short definition or an allusion to a well-taught prototype example. Do you remember prototypes? They are typical normal instance of a concept, for mammals a cow.
5. Provide spaced study, distributed practice. That means you provide review and practice over a period of several lessons. If there is no spaced study, the student is likely to confuse similar concepts, fail to integrate new knowledge into sequences of cognitive skills, and be slow to move new skills from demanding total attention into automatic execution.
6. Provide the user with control over the program, so that through a menu line, he or she can call up glossaries, lists of principles, summaries, examples. Then after studying, let the user return to the same place in the module. Some material from PLATO CAI programs does this, and so does a prototype of the new IBM Info-Window.

These six practices help people adjust to limits in their speed and in the capacity of their cognitive processing.

GOALS AND STANDARDS

What else can cognitive psychology contribute to the construction of a CAI lesson? There is a fair amount of research about the role of people's goals and standards in their cognitive processing. Here are some findings. If people set goals for themselves, they tend to act until they define that they have accomplished them. If they set high standards for their goals, they tend to work longer and accomplish more than if they define the standard lower. Similarly with thinking and memory. People's goals and sub-goals organize their thinking, remembering, and problem-solving. If people get interested in retrieving information from memory about a topic, a search occurs until it satisfies them or they conclude that they are not going to find it. If their specific goal were discrimination, for example, to distinguish between two superficially similar concepts such as negative reinforcement and a punishing stimulus, they would study their definitions and examples until they distinguished the difference.

But if people have vague goals, they accomplish less. The passivity of many students makes their real goals to be to do what the CAI program asks

them to do, to read this material, to answer that question. These vague goals confuse students and lead them to quit working before they have accomplished such goals as discriminating among similar concepts, generalizing to new instances, being able to retrieve new knowledge from memory despite cognitive interference from other learning, and developing cognitive skills that are practiced and integrated into smooth unities.

Encoding Specificity -- Match Teaching to Test: An important property of goals relates to the encoding specificity phenomenon. It says: "The probability of recalling an item at test depends on the similarity of its encoding at test and its original encoding at study." In practical terms it means that if the contextual stimuli at learning and recall are similar, a person is more likely to recall what he or she studied. If a person who is trying to learn something can create conditions while learning that roughly match the conditions that will be present when the item is being recalled, then learning is superior. This phenomenon occurs with any stimuli present when you learn a fact: the room you learned it in, the mood you felt, the other sights and sounds. The encoding specificity phenomenon can also backfire. When students learn material in a narrow context, and later have to use it in a different situation, they may fail to generalize it to new situations. After all, if people's grades on a test are lower merely because they take it in a different room than they learned the subject in, then it can occur with more important differences. It may mean that people who learn material from books and computer terminals need special teaching in order to ensure transfer of their knowledge and skills to real-world situations.

Goals -- Good Stimuli to Start From: An instructor can partly overcome this problem by engaging people's goals while studying. If you will be doing a task that needs to be guided by remembered facts, the task's demands become your goals and make you desire to recall them from your memory. When you are learning what the facts are, you have a better chance of remembering them later (when a task makes you need them and feel a desire to recall them) if you learn them by first desiring the facts and then seeing the wanted information. One response leads to another. The person's response of wanting a goal leads to the response of accessing information, both when learning and recalling.

This linkage of goals to memory means that when writing CAI lessons, it is helpful to communicate the instructional objectives to the students. Many of you may be thinking of behavioral objectives at this point -- the list of goals that occurs at the beginning of a lesson module and which is not referred to again. But there is a little more to it. The objectives must become the active goals of the students.

When a person thinks of his or her goal and feels that pull that communicates "I want this", that feeling is a response that is linked to added responses. So in education the trick is to help students use educational objectives as stimuli that elicit their responses of wanting goals and therefore trigger useful learning behavior or memory retrieval or skill practice. It is my impression that in many CAI programs the objectives don't do this. We don't want instructional goals to be dead formal statements that students cannot use. And that becomes the case if the CAI module takes too much control of the student's learning. Such control converts the student's goal into the task of obeying instructions. It prevents the student from

using the goal to guide his or her own cognitive processing. People use goals to tell when they are done with a task. And they also use the step by step instructions and tasks in a CAI module to tell when they are done. The two can conflict.

Goals have other uses. We want to prevent students from falsely believing they have learned something when they haven't. Therefore, it's helpful to integrate goals into CAI modules. For example, you could actually tell students the various sub-goals of concept learning. As you present some positive and negative examples in order to teach a new concept, you can write, "Study these examples until you can see why each one fits or violates the concept." (Positive and negative examples.) "Study these three concepts until you can precisely tell the difference among them." (Discrimination.) "You should be able to use this definition and these examples to develop the skill of identifying new examples of the concept." (Generalization.) "Memorize this particular example as a typical instance of this category, so that when you hear the name, you can mentally see this example." (Prototype example.)

How to Arouse Goals: It is easier said than done to get students to psychologically accept goals. Since many students don't care about accomplishing the instructional objectives proposed for them, it can often be a problem in CAI. Therefore, it is useful for a CAI program to be able to arouse motivation, even mild desire to learn something, from within the program. There is a simple method available, which it doesn't take cognitive psychology to know, that can arouse the desire for information.

First the general principle: When a person attempts to do a task and is interrupted or prevented from completing it, the person undergoes autonomic arousal and experiences a desire to complete the task. If lack of necessary knowledge caused the block, the person will develop a desire for that knowledge and will be interested in learning it later. It is well known that many people's early failures lead to life-long interests.

Here is one application: Suppose a CAI module deliberately taught incompletely the way to discriminate several concepts and gave students the task of taking a series of examples and identifying which concepts they were instances of. The students would naturally make a series of mistakes. These mistakes, interruptions, discrepancies, would make the students emotionally aroused, feel a desire for the specific information that would permit them to identify concepts and instances accurately, and would make them alert for any information that promised to accomplish the goal. In other words, the students would want the instructional goal of learning how to make that discrimination. Next the CAI program announces that shortly it will present the information that will satisfy that frustrated goal. If at that point the CAI module presented the missing information, the students would be likely to notice it, to place it in the correct context in their memories, and to be able to retrieve it later. Which is precisely what every good teacher wants.

Now my example is a little cruel to students, I think. There is a gentler way to arouse students' desire for information and to get the benefits of greater learning. Suppose a module had already taught a series of concepts, facts and skills. And in order to develop the skill of handling another type of problems, the next job were to teach a new concept or

principle. The CAI module could describe an example of that new class of problems, analyze it with the presently available concepts, and show that the present concepts cannot solve the problem and that the students need new information. Then the CAI writer can promise that that information is forthcoming. Then it would be presented.

Basically, what you do is show (1) that there is in existence a category of knowledge or a skill that the student does not have and that the category is useful; (2) you announce that you will present the information and that it will solve the problem; (3) you present it; (4) the student studies it and practices. I call it the "useful empty category" principle. The writers of detective stories do it when they present a mystery, give you a clue, get information and use it to make the mystery deeper, give more information after a struggle and make the mystery still deeper and so on. Paradoxes, opposites, seeming impossibilities will all do the job.

What happens if CAI presents new information without advertizing the troubles you'd have without it? Then the student has to work on faith, un-motivated, without a specific goal. And students who do not desire knowledge have one less cue for recalling it later.

REMEMBERING AND FORGETTING

Findings about memory have many implications for CAI programs. CAI programs should work consistently with the laws of memory rather than against them. When they do, the fortunate students can work through material faster, handle a larger amount of material, remember it longer, and integrate it better into cognitive skills. When we dig channels for water, it flows efficiently where we want it to. The following 5 principles concern material that is meaningful, material that is organized, people doing elaborated processing, 2 causes of forgetting -- trace decay and interference --, and once again matching people's learning conditions to retrieval conditions.

Principle #1. People remember material that is meaningful to them better than material that is arbitrary. What does meaningful mean? People start out feeling they understand certain familiar things. If they can translate the new into the familiar, then it is meaningful. Instructions are meaningful if people know what to do with them. Words are meaningful if they call up appropriate mental images, kinesthetic memories, sounds, and other well-learned concepts. And facts become meaningful for people if they can understand why the facts have to be what they are. For example, suppose students need to remember that arteries differ from veins in that arteries are thick and flexible whereas veins are thin and rigid. If they are told that arteries must absorb the force of the heart beat and expand under the pressure, then the thickness and flexibility become meaningful. New words can be made meaningful by providing puns and visual imagery for them. For example, the French word "chien" means dog. Chien sounds to me like shin, the lower part of my leg, which I can visualize. If I imagine a dog biting my shin, I've turned a meaningless set of sounds into a meaningful and memorable image. That's the essence of the famous and powerful keyword method of learning words. Once again, the principle: It is much easier for people to remember meaningful material than arbitrary material.

Principle #2. If material is presented in an organized, unified, integrated

way, then it is easier for people to remember it. Thus outlines, diagrams, charts, summaries, integrative analogies, and such aids all increase memory. A good example of this comes from an experiment done by Bat-Sheva Eylon,a graduate student of physicist and cognitive psychologist Philip Reif. She wrote a version of a textbook chapter on buoyancy, Archimedes principle. She wrote it in a hierarchical structure and explained how the topic fit into a broad overview of physics. Compared to a matched, conventional, good textbook chapter, students using it showed 40% greater recall and scored 25% higher in actual problem-solving. That's the power of presenting material so that students understand its organization.

Principle #3. If people do elaborated processing with new material, they remember it better than if they merely recite it. Elaborated processing means any activity that explores material and relates it to other material. Some examples of it are looking at details, comparing an item to something else, studying examples, classifying an example into the categories it relates to, thinking of personal associations, and considering how it fits into the overall pattern of the subject. Research has shown that if people do their own elaborated processing, their memory increases. And under some conditions it also works for teachers and books (and CAI) to supply the elaborated processing. Especially when teaching people new skills and procedures, it helps students to have many examples of how to do the skill. It reminds me of a pronouncement of Jerry Pournelle, the science-fiction writer who also writes the User's Column in BYTE, a computer magazine. He says in relation to computer manuals: "You can never have too many examples." That's elaborated processing for skills.

Much CAI neglects elaborated processing because it dutifully follows operant conditioning principles of giving repetition and reinforcement. Of course, it works, but it's slow. Like water in poorly dug channels. It would be wiser to provide elaborated processing or to induce the students to do it themselves. One warning: If the students cannot distinguish the elaborations from the main line of instruction, it turns out worse than by merely providing bare outlines!

Principle #4. When a person's conditions at learning match conditions at retrieval, memory is better. I cited this finding before in connection with instructional goals. If you desire to know a fact when learning it, then later when you feel a similar desire to recall the fact, you are likely to recall it. Lets extend the finding to how information gets written. CAI can also write its material in ways that match test conditions later. Writers should sequence material in sentences and paragraphs in ways that match real-life sequences. In real life you will first be wanting to reach a goal and you'll see a set of stimuli before you make your response. So a CAI writer should describe the goal and stimuli first and the proper response second.

Here's a bad example: An Electronics program talks about safety hazards. "Never change components with power on . . ." It's better to say, "If you want to change components [goal] and you see that the power is on [stimulus)] turn it off [response] and then change components [response]."

Another bad example: "Always use an isolation transformer when working with any equipment of the hot-chassis type." It's better to say: "If you see

that you must work with equipment of the hot-chassis type [stimulus], then always use an isolation transformer [response]." These better forms write the goal and stimulus first, then write the student's response.

Principle #5. Trace decay and interference both cause forgetting. Trace decay means some sort of erosion of the memory trace over time. Interference is what happens when things learned later interfere with attempts to recall earlier learning, and vice versa, when the earlier interferes with recalling the later. When students learn a lot in CAI, there's interference. And when they take a break of several days between working on modules, there occur both trace decay and interference. Some cures for interference are overlearning, good discrimination training, and distributed study, whereby the same material is studied and practiced a number of times on different occasions.

Some Applications of Memory Principles: What are some applications to CAI of these memory principles considered together?

One of the dangers of CAI material is that a student encounters a series of separate topics, very finely subdivided. When a CAI writer has done a good task analysis for sub-skills and prerequisite knowledge, this excellent practice can sometimes violate the principle of organization. How do we improve?

First, it would seem to help if the program provides overviews, abstracts, introductory summaries of principles, diagrams of topics, and so on. As each new topic is introduced, the program might return to an overview diagram and show how the new topic is related to the whole.

Second, tutorials could provide several passes through the same material, each time getting more detailed. Some cognitive psychologists now organize material this way.

Third, the useful empty category method could be used to link the need for information or a skill to the forthcoming lessons.

Fourth, even instructional goals could be organized and students could be referred to them throughout.

Give Students Control Over Access to Information: Several principles suggest that giving students more control over access to information in programs would improve both their understanding and their memory. Unfortunately, many CAI programs only give users control over sequential movement and exit, according to a recent study. Yet the newer microcomputers have adequate disk storage for large data bases. They allow the possibility of students asking for specific information as they need it.

Imagine a student studying an English grammar lesson. It contains several of the dozen principles about using semi-colons and commas correctly. After reading the lesson or working the programmed examples, the person does some drill and practice. At the bottom of the screen there is printed a permanent menu line, accessible by hitting the slash key. The menu contains items like A glossary, index, review a topic, lists of rules etc. The student comes to an item about using commas in a series and he or she has forgotten it. If the student guesses until the right answer is hit, the student

violates the principle of meaningfulness. So the student hits the slash key, asks for a list of principles, retrieves a sub-menu listing several topics, commas included, and asks for the comma principles. The student reads the list, finds the forgotten comma-in-series information, hits a key to return to the drill and practice item, and answers the item correctly.

What has happened? The student's need for information about comma principles to solve a specific problem has triggered a goal to know that information. The student is able to ask for it easily and retrieve it and use it in the correct context. And the program can immediately report whether he or she used it correctly or not so that reinforcement or correction occurs. This learning experience mimics that student's real life experience next week in writing a letter. She wonders, "What is the rule about commas in series?" It's the same goal, the same stimulus, experienced before and it has been conditioned to an act of retrieving of that information. Thus the student has a higher probability of finding that information in memory than if he or she were given no control over the program. A variant of this procedure could require the student to guess at the principle, to type it in, before seeing it. Again the procedure mimics real-life memory search.

And we can make this phenomenon still more useful by providing students with constant review that keeps asking about previously learned material in current lessons. That mimics real-life needs for knowledge, where the demand for information can occur anytime. And if a student has access on-demand to indexes, reviews, glossaries of terms, worked out problems, examples, lists of principles, lists of concepts and prototype examples, and so on, the student can easily answer questions. Students who study with books or with private tutors have the same control over their material.

Naturally, we could build ways to reward students for making a successful memory search and ending their dependence on the lookup procedure. It will partly happen anyway. For example, users of word-processing programs use on-line help for awhile, eventually remember commands and stop using it.

This lookup procedure also fights memory's enemy: interference. When there is much material to be learned, students keep forgetting previously learned material. If drill and practice and problems keep demanding prior material, the student is constantly asked to access it and use it in cognitive skills. And if a student can look up forgotten material easily within the program's attached data bases, then the constant review is not threatening to a student. It would become feasible for students who study material for which they have only some of the prerequisite skills to have a chance at it. Also it would become feasible for students who have let a big lapse of time go by to return to a program without the penalty of doing a lock-step review of prior lessons.

The findings about interference and forgetting combined with the earlier ones on learning to discriminate between concepts and to generalize to new instances suggest another application to CAI. Consider subjects like English grammar and mathematics. Both of them are taught by having students produce their own work. English teachers assign essays, then correct them. Math teachers assign problems and correct them. These teaching methods create built-in limits to the number of possible times students can practice their cognitive skills and discriminate among the concepts and procedures they are

learning. Also it is difficult for CAI programs to evaluate constructed answers, although the excellent work being attempted now may overcome these difficulties eventually.

Edit-and-Correct Practice: Suppose programs provided "edit and correct" practice. A math program might provide a series of already worked-out problems and answers. Each line is numbered, and each line could be correctly worked or in error. The student's task is to decide whether each line is correct or wrong. If an early line is wrong and introduces a mistake, the student would evaluate later lines assuming the values were consistent with the mistake. After each decision or each block of decisions, feedback is provided. In addition, the student could call up the relevant principles and relevant prototype example problems. After CAI practice would come real start-to-finish problem-solving by the student.

This kind of practice has a number of properties that use natural processes helping memory. First, it would mimic the mind's natural process of seeing problem data, perceiving concept characteristics and discriminating among them, searching for applicable math procedures, applying them and creating a new state of the problem and evaluating it again. Teachers see thousands of student problems and have to go through the same process. It may be one reason why they get so good. Second, this kind of practice would permit a student to get 5 or 10 times as many chances to practice a discrimination and a cognitive skill and get feedback as would solving problems personally. Third, each problem fosters concept learning by providing additional positive and negative examples of concepts and procedures and builds discrimination and generalization. And having lists of principles and prototypes available helps the student to think mathematically.

Teach Good Study Methods: Finally, some of these memory principles suggest that CAI lessons should perhaps teach study skills. We shouldn't take it for granted that students studying at a computer terminal know how to learn and remember. It probably would be feasible for the League for Innovation to produce a high quality CAI lesson on memory and study techniques that can be distributed at cost to producers of CAI material. It could be linked via menus to the main programs. Certainly, material on memory should discuss such topics as learning concepts, skills, terminology, and facts. It should describe the keyword method of memorizing, distributed study, elaborated processing, self-testing, and cumulative addition to a set.

I have only touched a few topics from cognitive psychology. There is much available on problem-solving, language comprehension, good writing, reasoning, mental models, intelligence, instructional design, motor skills learning, and mental chronometry--the time it takes to do things. I believe the time taken to explore this rich and fascinating area will be very rewarding. We should continue to watch this field closely. And perhaps the League for Innovation should commission a handbook containing relevant psychological findings and suggested applications.

BIBLIOGRAPHY OF SOME BOOKS I HAVE FOUND ESPECIALLY USEFUL
ON COGNITIVE PSYCHOLOGY, TEACHING, AND MOTIVATION

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Carroll, David W., Psychology of Language. Monterey, CA: Brooks/Cole, 1986. (Describes findings on comprehension, language production, and learning language. Contains applications to many teaching and learning topics. Well-written and interesting.)

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SUMMARY OF RECOMMENDED PRACTICES
Taken from the speech:

HOW THE USE OF COGNITIVE PSYCHOLOGY FINDINGS CAN RAISE THE PRODUCTIVITY OF CAI

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When a person starts out to write a computer-assisted instruction program, he or she wants to know how to write it so that students learn efficiently and effectively. Similarly, teachers who are evaluating CAI programs need to know what features signal a program that teaches effectively or poorly. They can find a lot of help by reading cognitive psychology books and articles. Cognitive psychologists have discovered many new and important principles that could greatly raise the productivity of CAI -- if CAI writers would use them.

Cognitive psychologists study the kinds of topics that fascinate teachers: learning concepts and skills, instructional design, remembering and forgetting, paying attention, discriminating among similar concepts, generalizing one's knowledge and skills from the learning examples to new situations, instructional goals, feedback, problem-solving, language comprehension, good writing, reasoning, mental models, intelligent behavior, and motor skills learning. People who write and use CAI can read this material and find many ways to improve their work.

The talk that this brief summary is based on tried to give a hint of some of the major findings in four areas and to suggest some techniques that CAI writers could use to help students learn more effectively. The areas chosen were concept learning; the capacity limits of mental processing; goals and how they organize people's thinking; and remembering and forgetting. Space in this summary does not permit a review of these findings here. But it is possible to sketch some of the practices that are consistent with cognitive psychology's discoveries.

Most current CAI seems to be based on classical conditioning and operant conditioning research. Classical conditioning is used in many tutorial and drill-and- practice programs that use knowledge that is familiar to students as the base to associate new stimuli to. Operant conditioning is used when programs induce students to act, to get rewards or punishments, and to act again. Many CAI programs subdivide lessons into little units, which are usually chosen and rationally sequenced on the basis of a task analysis of sub- skills and prerequisite knowledge that students need for success. Brief expositions and examples are given. Then practice, feedback and testing are prescribed. It should be noted that the author easily found CAI modules which violated, or at best neglected, the principles of classical and operant conditioning, thus weakening their power to instruct.

Cognitive psychology principles also suggest a number of additional

instructional practices. Here is a sample list.

1. When teaching concepts, present a set of positive examples that taps the major range of instances that fit the concept. Purpose: To help students generalize to new examples.

2. Present a set of negative examples that cover the major concept criteria. Purpose: To help students discriminate among superficially similar concepts.

3. Identify at least one positive example of a concept as a memorable prototype example. Urge the students to memorize it. Link it to the definition. Purpose: To assist memory by supplementing hard-to-remember abstract definitions in words with more concrete and visual material.

4. Introduce new concepts one or two at a time. Avoid introducing too many new things at once. Purpose: To prevent overload of short-term memory.

5. Use cumulative addition to a set. Introduce new concepts, provide practice on them, and then add another concept, and practice it with the earlier ones. And so on for later concepts. Don't introduce concepts and have practice on them only in isolation from other concepts and knowledge. Purposes: To prevent memory overload and to provide discrimination practice. To fight "interference" whereby new material interferes with memory of older material and vice versa.

6. When the CAI program refers to a concept that may have been forgotten, provide a brief reminder by citing the definition or alluding to the prototype example. Purpose: To compensate for the fading of items from short-term memory.

7. Provide spaced study, distributed practice, and embedded review of material over several lessons. Don't confine the practice of new skills within one module. Purpose: To improve memory, integrate new and old material, and prevent interference.

8. Provide the user with control over the program. Let the student use a menu line or function keys to call up glossaries, lists of principles and facts, summaries, and examples. Let the user review past modules quickly, skipping practice. Purpose: To cope with normal forgetting and long delays between lessons. To let the user build personal associations among items. This is very helpful and is recommended.

9. Try to arouse the students' motivation to want to accomplish the program's instructional goals. This can often be done by demonstrating a task that the student cannot do with present knowledge and skills. Then promise that the coming module or practice will provide the missing needed knowledge and skills. You show a problem, you announce you will solve it, then you demonstrate the solution, and then you provide practice. Don't make a habit of presenting information without demonstrating the need for it.

10. Define instructional goals in two ways: (1) The ultimate goal, and

(2) the short-term sub-goal that the learner should accomplish in the current lesson. Purpose: To link attainable sub-goals in a sequence that leads to overall goals. To prevent students from feeling like failures because they cannot accomplish the overall goal immediately.

11. When describing instructional goals to students, also describe the ways that students can tell whether they are achieving the goal. Purpose: To allow students to generate feedback by themselves independently of the program. To improve motivation and learning.

12. Make the sequence of goals, stimuli and desired responses that occur in instruction match the sequence that will be used later by tests and real-life tasks. Purpose: To increase students' ability to generalize from the learning situation to the test.

13. Make presentations meaningful by using visual, auditory, kinesthetic language. Explain why facts have to be what they are. Link the new to the familiar. Purpose: To increase memory by using the principle that people remember meaningful material better than arbitrary material.

14. Present material in an organized way and explain to the students the principles of the organization. When presenting a topic, also link it to the larger organization. Purpose: To make use of the fact that organized material is more easily recalled than is unorganized material.

15. Help the students do elaborated processing with the material. Help them to analyze wholes into their parts, to compare items to others, to study examples, to classify examples into the categories the relate to, and to think of personal associations. Purpose: To use the findings that show that people's elaborated processing greatly helps memory.

16. Provide "edit and correct" practice. When moving from a tutorial to student practice, provide an intervening step before requiring students to solve their own problems. Provide a series of worked examples containing a series of numbered steps. Make some steps right and others wrong. Make the students' task be to identify which steps are done right or wrong. Let the worked examples contain a range of positive and negative examples of applications of principles. It would also be useful to provide students with access to lists of principles and prototype examples as they work these "edit and correct" items. This can be used for teaching problem-solving tasks and creating correct sequences of actions. Useful in English and foreign language grammar practice, and in math and science problem-solving. Purpose: To provide the students with many examples of discrimination practice and feedback that occur rapidly. It saves them time when they do their own work and problem-solving.

17. Provide the students with how-to-study advice in the program. Many students work on a program and go passive, and they inadvertently learn more slowly than necessary.

Although each of these suggestions is derived from cognitive psychology principles that are supported by research findings, each will work better in

some situations than in others. It's also possible that some will have undesirable side effects and some will take a lot of time to develop. Nevertheless, because they are based on forces that have power to increase learning, they will usually help students learn better than when they are not used. CAI writers should use them as a carpenter uses tools appropriate to each situation. Moreover, there are many more applications to teaching from cognitive psychology that come from areas not touched in the talk. The interested reader who searches cognitive psychology research will find valuable material that can assist in all teaching tasks.

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